NASA-CR-192989

PROMISC USER MANUAL

Prepared by:

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Thomas B. Lovelace

APPENDIX 2
of Final Technical Report
of Project Entitled
Development of Advanced Methodologies
for Probabilistic Constitutive Relationships
of Material Strength Degradation Models, Phase 2

NASA Grant No. NAG 3-867

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Cleveland, OH 44135

The Division of Engineering
The University of Texas at San Antonio
San Antonio, TX 78285
January, 1990

Vers. 2.0

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1.0 INTRODUCTION

This User Manual documents the FORTRAN program PROMISC. The program performs a multiple linear regression on actual experimental or simulated experimental data for as many as eighteen effects or primitive variables, yielding regression coefficients that are the empirical material constants, a_i, required by PROMISS (see Section 2.0, Theoretical Background).

Included in this User Manual are details regarding the theoretical background of both PROMISS and PROMISC, input data instructions and sample problems illustrating the use of PROMISC. Appendix A gives information on the primitive variables, their symbols, FORTRAN names and both SI and U.S. Customary units. Appendix B includes a disk containing the actual input and output files corresponding to the sample problems. The source code is available from the author at the address given on the cover page of this report. Appendix C details the IMSL, Version 10 [1], subroutines and functions called by PROMISC.

2.0 THEORETICAL BACKGROUND

Recently, a general phenomenological constitutive relationship for composite materials subjected to a number of diverse effects or primitive variables has been postulated to predict mechanical and thermal material properties [3,4,5,6]. The resulting multifactor interaction constitutive equations summarize composite micromechanics theory and have been used to predict material properties for a unidirectional fiber-reinforced lamina, based on the corresponding properties of the constituent materials.

These equations have been modified to predict the mechanical property of strength for one constituent material due to "n" diverse effects or primitive variables. These effects could include both time-independent and time-integrated primitive variables, such as mechanical stresses subjected to both static and impact loads, thermal stresses due to temperature variations and thermal shock, and other effects such as chemical reaction or radiation attack. They might also include other time-dependent primitive variables such as creep, mechanical fatigue, thermal aging, thermal fatigue, or even effects such as seasonal attack (see Appendix A, Primitive Variables, Symbols, and Units). For most of these primitive variables, strength has been observed to decrease with an increase in the variable.

The postulated constitutive equation accounts for the degradation of strength due to these primitive variables. The general form of the equation is

$$\frac{S}{S_O} = \prod_{i=1}^{n} \left[\frac{A_{iF} - A_i}{A_{iF} - A_{iO}} \right]^{a_i}, \qquad (1)$$

where A_i, A_{iF} and A_{iO} are the current, ultimate and reference values of a particular effect, a_i is the value of an empirical constant for the i^{th} effect or primitive variable, n is the number of product terms of primitive variables in the model, and S and S_O are the current and reference values of material strength. Each term has the property that if the current value equals the ultimate value, the current strength will be zero. Also, if the current value equals the reference value, the term equals one and strength is not affected by that variable.

This deterministic constitutive model may be calibrated by an appropriately curve-fitted least squares multiple linear regression of experimental data [7], perhaps supplemented by expert opinion. Ideally, experimental data giving the relationship between effects and strength is obtained. For example, data for just one effect could be plotted on log-log paper. A good fit for the data is then obtained by a linear regression analysis. This is illustrated schematically in Figure 1. The postulated constitutive equation, for a single

effect, is then obtained by noting the linear relation between log S and $\log\left[\frac{A_F - A_O}{A_F - A}\right]$,

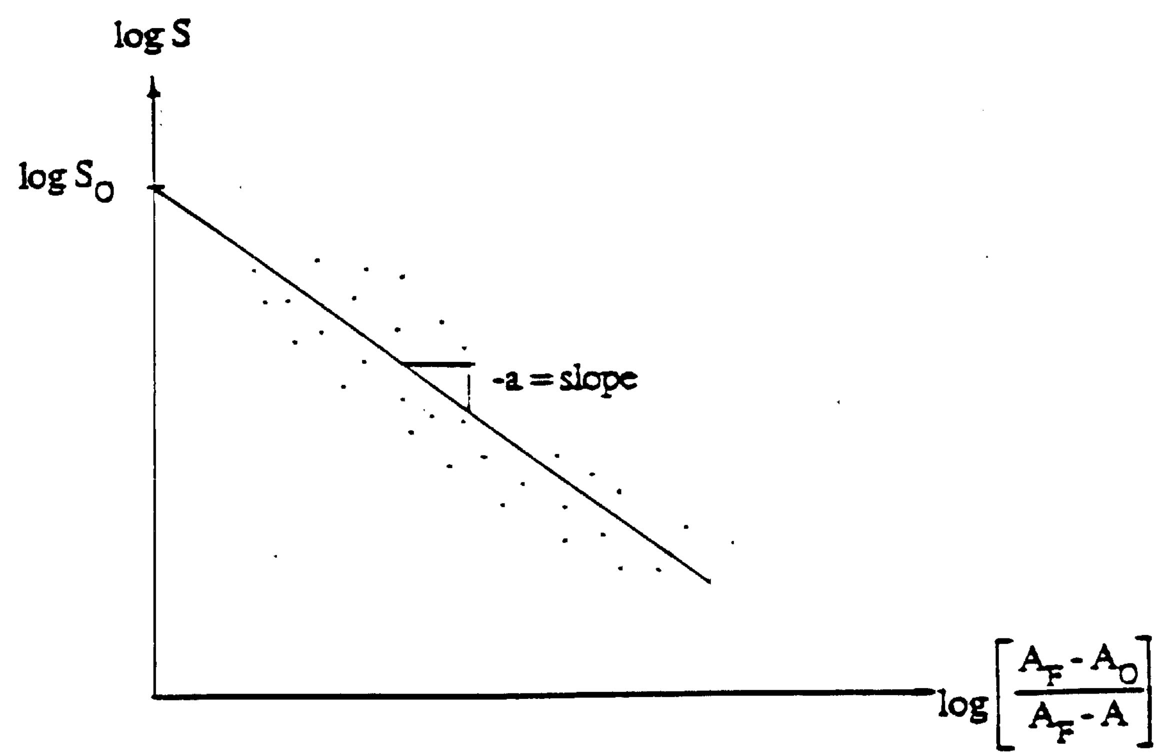

Fig. 1 Schematic of experimental data illustrating the effect of one primitive variable on strength.

as follows:

$$\log S = -a \log\left[\frac{A_F - A_O}{A_F - A}\right] + \log S_O$$

$$\log S - \log S_O = -a \log\left[\frac{A_F - A_O}{A_F - A}\right]$$

$$\log \frac{S}{S_O} = -a \log\left[\frac{A_F - A_O}{A_F - A}\right]$$

$$\frac{S}{S_O} = \left[\frac{A_F - A_O}{A_F - A}\right]^{-a}$$

$$\frac{S}{S_O} = \left[\frac{A_F - A}{A_F - A_O}\right]^{a}. \qquad (2)$$

Note that the above equation (2) is for a primitive variable that lowers strength. If a variable raises strength, the exponent is negative.

This general constitutive model may be used to estimate the strength of an aerospace propulsion system component under the influence of a number of diverse effects or primitive variables. The probabilistic treatment of this equation includes randomizing the deterministic multifactor interaction constitutive equation, performing probabilistic analysis by simulation and generating probability density function (p.d.f.) estimates for strength using a non-parametric method, maximum penalized likelihood [8,9]. Integration yields the cumulative distribution function (c.d.f.) from which probability statements regarding strength may be made. This probabilistic constitutive model predicts the random strength of an aerospace propulsion component due to a number of diverse random effects.

This probabilistic constitutive model is embodied in two FORTRAN programs, PROMISC (Probabilistic Material Strength Calibrator) and PROMISS (Probabilistic Material Strength Simulator); see Final Technical Report, APPENDIX 1. PROMISS calculates the random strength of an aerospace propulsion component due to as many as eighteen diverse random effects. Results are presented in the form of probability density functions and cumulative distribution functions of normalized strength, S/S_O. PROMISC calculates the values of the empirical material constants, a_i.

PROMISS (see Final Technical Report, APPENDIX 1) includes a relatively simple "fixed" model as well as a "flexible" model. The fixed model postulates a probabilistic constitutive equation that considers the primitive variables given in Table 1. The general form of this constitutive equation is given in equation (1), wherein there are now n = 7 product terms, one for each effect or primitive variable listed above. Note that since this model has seven primitive variables, each containing four values of the variable, it has a total of twenty-eight variables. The flexible model postulates a probabilistic constitutive equation that considers up to as many as n = 18 product terms for primitive variables. These variables may be selected to utilize the theory and experimental data currently available for the specific strength degradation mechanisms of interest. The specific effects included in the flexible model are listed in Table 2. Note that in order to provide for future expansion and customization of the flexible model, six "other" effects have been provided.

Table 1 Primitive variables available in the fixed model

i^{th} Primitive Variable	Primitive Variable Type
1	Stress due to static load
2	Temperature
3	Chemical reaction
4	Stress due to impact
5	Mechanical fatigue
6	Thermal fatigue
7	Creep

Table 2 Primitive variables available in the flexible model

A. Environmental Effects

1. Mechanical
   a. Stress
   b. Impact
   c. Other Mechanical Effect

2. Thermal
   a. Temperature Variation
   b. Thermal Shock
   c. Other Thermal Effect

3. Other Environmental Effects
   a. Chemical Reaction
   b. Radiation Attack
   c. Other Environmental Effect

B. Time-Dependent Effects

1. Mechanical
   a. Creep
   b. Mechanical Fatigue
   c. Other Mech. Time-Dep. Effect

2. Thermal
   a. Thermal Aging
   b. Thermal Fatigue
   c. Other Thermal Time-Dep. Effect

3. Other Time-Dependent Effects
   a. Corrosion
   b. Seasonal Attack
   c. Other Time-Dep. Effect

The considerable scatter of experimental data and the lack of an exact description of the underlying physical processes for the combined mechanisms of fatigue, creep, temperature variations and so on, make it natural, if not necessary to consider probabilistic models for a strength degradation model. Therefore, the fixed and flexible models corresponding to equation (1) are "randomized", and yield the "random normalized material strength due to a number of diverse random effects or primitive variables." Note that for the fixed model, equation (1) has the following form:

$$S/S_O = f(A_{1F}, A_1, A_{1O}, A_{2F}, A_2, A_{2O}, \ldots, A_{7F}, A_7, A_{7O}) \qquad (3)$$

where A_i, A_{iF} and A_{iO} are the ultimate, current and reference values of the i^{th} of seven effects or primitive variables as given in Table 1. In general, this expression can be written as,

$$S/S_O = f(X_i),\ i = 1, \ldots, 28, \qquad (4)$$

where the X_i are the twenty eight independent variables in equation (3). Thus the fixed model is "randomized" by assuming all the independent variables, X_i, $i = 1, \ldots, 28$, to be random and stochastically independent. For the flexible model, equation (1) has a form analogous to equations (3) and (4), except that there are as many as seventy-two independent variables. Applying probabilistic analysis to either of these randomized equations yields the distribution of the dependent random variable, normalized material strength, S/S_O.

Although a number of methods of probabilistic analysis are available, [8] simulation was chosen for PROMISS. Simulation utilizes a theoretical sample generated by numerical techniques for each of the independent random variables. One value from each sample is substituted into the functional relationship, equation (3), and one realization of normalized strength, S/S_O, is calculated. This calculation is repeated for each value in the set of samples, yielding a distribution of different values for normalized strength.

A probability distribution function is generated from these different values of normalized strength using a non-parametric method, maximum penalized likelihood. Maximum penalized likelihood generates the p.d.f. estimate using the method of maximum likelihood together with a penalty function to smooth it [9]. Finally, integration of the generated p.d.f. results in the cumulative distribution function, from which probabilities of normalized strength can be directly observed.

PROMISS includes computational algorithms for both the fixed and the flexible probabilistic constitutive models. As described above, PROMISS randomizes the following equation:

$$\frac{S}{S_O} = \prod_{i=1}^{n} \left[\frac{A_{iF} - A_i}{A_{iF} - A_{iO}} \right]^{a_i}, \qquad (5)$$

where

$$\left[\frac{A_{iF} - A_i}{A_{iF} - A_{iO}}\right]^{a_i}$$

is the i^{th} effect, A_{iF}, A_{iO} and A_O are random variables, a_i is the i^{th} empirical material constant and S/S_O is normalized strength. There are a maximum of eighteen possible effects or primitive variables that may be included in the model. For the flexible model option, they may be chosen by the user from those in Table 2. For the fixed model option, the primitive variables of Table 1 are chosen. Within each primitive variable term the current, ultimate and reference values and the empirical material constant may be modeled as either deterministic (empirical, calculated by PROMISC), normal, lognormal, or Wiebull random variables. Simulation is used to generate a set of realizations for normalized random strength, S/S_O, from a set of realizations for primitive variables and empirical material constants. Maximum penalized likelihood is used to generate an estimate for the p.d.f. of normalized strength, from a set of realizations of normalized strength. Integration of the p.d.f. yields the c.d.f. Plot files are produced to plot both the p.d.f. and the c.d.f. PROMISS also provides information on S/SO statistics (mean, variance, standard deviation and coefficient of variation). A resident database, for database rather than user input of empirical material constants, is also provided.

PROMISC performs a multiple linear regression on experimental data for as many as eighteen effects or primitive variables, yielding regression coefficients that are the empirical material constants, a_i, required by PROMISS.
It produces the multiple linear regression of the log transformation of equation (3), the PROMISS equation. When transformed it becomes

$$\log \frac{S}{S_O} = \sum_{i=1}^{18} a_i \log\left[\frac{A_{iF} - A_i}{A_{iF} - A_{iO}}\right], \qquad (6)$$

or

$$\log S = \log S_O + \sum_{i=1}^{18} a_i \log\left[\frac{A_{iF} - A_i}{A_{iF} - A_{iO}}\right], \qquad (7)$$

where

$$\left[\frac{A_{iF} - A_i}{A_{iF} - A_{iO}}\right]^{a_i}$$

is the i^{th} effect, A_i, A_{iF} and A_{iO} are primitive variable data and a_i is the i^{th} empirical material constant, or the i^{th} regression coefficient to be predicted by PROMISC. Also, $\log S_O$ is the log transformed reference value of strength , or the intercept regression coefficient to be predicted by PROMISC, and log S is the log transformed strength. Experimental data for up to eighteen possible effects, as given in Table 2, may be included. The primitive variable data may be either actual experimental data or expert opinion, directly read from input, or simulated data where expert opinion is specified as the mean and standard deviation of a normal or lognormal distribution. The simulated data option for input data was used in the early stages of code development to verify correct performance. The input data, whether actual or simulated, is read in and assembled into a data matrix. From this data matrix, a corrected sums of squares and crossproducts matrix is computed. From this sums of squares and crossproducts matrix, and a least squares methodology, a multiple linear regression is performed to calculate estimates for the empirical material constant, a_i, and the reference strength, S_O. These are the regression coefficients.

PROMISC includes enhancements of the multiple linear regression analysis to screen data from "outliers" and collinearities, determine "how well" the data fit the regression, quantify the importance and relative importance of each factor in the postulated constitutive equation, eq. (1), as well as check assumptions inherent in the use of multiple linear regression. Further details are provided in the Final Technical Report, Section 6.0, NASA Grant No. NAG 3-867, Supp. 2, "Probabilistic Lifetime Strength of Aerospace Materials via Computational Simulation."

3.0 SAMPLE PROBLEMS AND INPUT DATA

Data input for PROMISC is user friendly and easy to enter. Actual experimental data can be input by the user or the user can select simulated experimental data. Two examples follow (see also Section 6.0, Appendix B).

3.1 PROMISC Input For Fixed Model With Actual Experimental Data (40 Data Points)

The 1st line of input (format 2E12.4, see item 1 below) determines the random number generator seed* and the data sample size. The 2nd line (format I3) determines either a fixed or a flexible model. The 3rd line (format I3) chooses the dependent variable as strength. The 4th line (format I3,2X,I3,2X,I3) determines the source of the data (actual experimental, normal or lognormal simulated data). The 5th through the 28th lines (format 5D12.4) specify the data for the primitive variables. This sequence of twenty-five lines repeats for the other primitive variables. Lastly, the 179th through the 187th lines specify the data for the strength variable. A table listing the primitive variables, their units and symbols is given in Section 5.0, Appendix A. IMSL parameters are entered as indicated in items 12 and 13.

1. Line 1 selects the Random Number Generator Seed (ISEED) and Sample Size (NTOT)

EXAMPLE:

```
12345678901234567890**
   1        40
```

2. Line 2 selects either Fixed or Flexible Model (MODEL = 0 is flexible, MODEL = 1 is fixed).

EXAMPLE:

```
12345678901234567890
  1
```

3. Line 3 selects strength as the dependent variable (DEPV = 1 is strength dependent variable, DEPV = 0 is not strength dependent variable).

EXAMPLE:

```
12345678901234567890
  1
```

* If actual experimental data are used (AFDS = 0; ADS = 0; AODS = 0) the random number generator seed, ISEED, is read in but not used in the program.

** NOTE: the ruler is to aid the user in formatting and is not a part of the input.

4a. Line 4 specifies the *source* of the data for the three variables within the Quasi-static Stress Effect by using flags. The flag names are AFDS, ADS and AODS. Setting a flag to 0 indicates actual experimental data is directly read from input. Setting a flag to 1 indicates simulated experimental data, normally distributed, is generated by the program via a random number generator. Setting a flag to 2 indicates simulated experimental data, lognormally distributed, is generated by the program via a random number generator. Setting a flag to 3 indicates data not available.

EXAMPLE:

```
12345678901234567890
    0       0       0
```

4b. Lines 5 to 28 contain the actual experimental data for the three variables within the Quasi-static Stress Effect. The Quasi-static Stress Effect variable names have FORTRAN names given in Section 5.0, APPENDIX A.

EXAMPLE:

```
123456789012345678901234567890123456789012345678901234567890
   0.1179D+03  0.1344D+03  0.1273D+03  0.1260D+03  0.1403D+03
   0.1292D+03  0.1295D+03  0.1241D+03  0.1265D+03  0.1229D+03
   0.1321D+03  0.1387D+03  0.1370D+03  031264D+03  0.1323D+03
   0.1278D+03  0.1269D+03...........etc.
```

(All of the values for this and other effects are too numerous to include in this description. See Section 6.0 APPENDIX B.)

5. Lines 29 to 53 input data for the Impact Effect in the same manner as was described for the Quasi-static Stress Effect. The Impact Effect variable names have FORTRAN names given in Section 5.0, APPENDIX A.

EXAMPLE:

```
12345678901234567890
   0       0       0
   0.9870D+00  0.9966D+00  0.1002D+01  0.9997D+00  0.1000D+01
   0.9977D+00  0.9950D+00  0.1001D+01  0.1001D+01  0.1005D+01
   0.9991D+00  0.1000D+01  0.1003D+01  0.9945D+00  0.9952D+00
   0.1000D+00  0.1001D+01............etc.
```

6. Lines 54 to 78 input data for the Temperature Effect in the same manner as was described for the Quasi-static Stress Effect. The Temperature Effect variable names have FORTRAN names given in Section 5.0, APPENDIX A.

EXAMPLE:

```
123456789012345678901234567890123456789012345678901234567890
   0       0       0
   0.2378D+04   0.2640D+04   0.2789D+04   0.2723D+04   0.2739D+04
   0.2668D+04   0.2598D+04   0.2770D+04   0.2770D+04   0.2856D+04
   0.2708D+04   0.2739D+04   0.2811D+04   0.2583D+04   0.2600D+04
   0.2738D+04   0.2768D+04..........etc.
```

7. Lines 79 to 103 input data for the Chemical Effect in the same manner as was described for the Quasi-static Stress Effect. The Chemical Effect variable names have FORTRAN names given in Section 5.0, APPENDIX A.

EXAMPLE:

```
123456789012345678901234567890123456789012345678901234567890
   0       0       0
   0.9870D+00   0.9966D+00   0.1002D+00   0.9997D+00   0.1000D+01
   0.9977D+00   0.9950D+00   0.1001D+01   0.1001D+01   0.1005D+01
   0.9991D+00   0.1000D+01   0.1003D+01   0.9945D+00   0.9952D+00
   0.1000D+01   0.1001D+01...........etc.
```

8. Lines 104 to 128 input data for the Creep Effect in the same manner as was described for the Quasi-static Stress Effect. The Creep Effect variable names have FORTRAN names given in Section 5.0, APPENDIX A.

EXAMPLE:

```
123456789012345678901234567890123456789012345678901234567890
   0       0       0
   0.9072D+04   0.1034D+05   0.9792D+04   0.9696D+04   0.1080D+05
   0.9936D+04   0.9959D+04   0.9544D+04   0.9733D+04   0.9450D+04
   0.1016D+05   0.1067D+05   0.1054D+05   0.9723D+04   0.1018D+05
   0.9827D+04   0.9758D+04.........etc.
```

9. Lines 129 to 153 input data for the Impact Effect in the same manner as was described for the Quasi-static Stress Effect. The Impact Effect variable names have FORTRAN names given in Section 5.0, APPENDIX A.

EXAMPLE:

```
1234567890123456789012345678901234567890123456789012345678 90
    0      0      0
    0.5749D+01  0.7465D+01  0.6696D+01  0.6565D+01  0.8136D+01
    0.6894D+01  0.6926D+01  0.6362D+01  0.6615D+01  0.6237D+01
    0.7214D+01  0.7947D+01  0.7752D+01  0.6602D+01  0.7235D+01
    0.6744D+01  0.6649D+01.........etc.
```

10. Lines 154 to 178 input data for the Thermal Fatigue Effect in the same manner as was described for the Quasi-static Stress Effect. The Thermal Fatigue Effect variable names have FORTRAN names given in Section 5.0, APPENDIX A.

EXAMPLE:

```
123456789012345678901234567890123456789012345678901234567890
    0      0      0
    0.2464D+01  0.3199D+01  0.2870D+01  0.2813D+01  0.3487D+01
    0.2954D+01  0.2968D+01  0.2727D+01  0.2835D+01  0.2673D+01
    0.3092D+01  0.3406D+01  0.3322D+01  0.2830D+01  0.3101D+01
    0.2890D+01  0.2850D+01.........etc.
```

11a. Line 179 specifies the source of the strength data by using flags. The flag names are AFDS, ADS and AODS. Setting a flag to 0 indicates actual experimental data is directly read from input. Setting a flag to 1 indicates simulated experimental data, normally distributed, is generated by the program via a random number generator. Setting a flag to 2 indicates simulated experimental data, lognormally distributed, is generated by the program via a random number generator. Setting a flag to 3 indicates data not available.

EXAMPLE:

```
1234567890
    0
```

11b. Lines 180 to 187 contain the actual experimental data for strength. The FORTRAN name for strength is STR.

EXAMPLE:

```
123456789012345678901234567890123456789012345678901234567890
    0.1117D+02  0.0855D+02  0.0735D+02  0.0786D+02  0.0774D+02
    0.0831D+02  0.0895D+02  0.0749D+02  0.0749D+02  0.0687D+02
    0.0798D+02  0.0776D+02  0.0719D+02  0.0906D+02  0.0891D+02
    0.0774D+02  0.0751D+02.........etc.
```

12. The CORVC [1] parameters are IDO, LDX, IFRQ, IWT, MOPT, ICOPT, LDCOV, and LDINCD and are entered in that order as follows (line 188):

EXAMPLE:

```
1234567890123456789012345678901234567890
     0  240     0     0     0     1    19    19
```

13. The RCOV [1] parameters are INTCEP, NOND, NDEP, LDCOV, LDB, LSR, and LDSCPE and are entered in that order as follows (line 189):

EXAMPLE:

```
1234567890123456789012345678901234567890
     1     7     1    19    19    19     1
```

3.1.1 Discussion of Results

Execution of PROMISC (source code entitled PROMISC5.FOR) produces an output file that gives computed values for the empirical material constants, a_i. Output also includes statistics and diagnostics that enhance the PROMISC multiple linear regression analysis (see Section 2.0, Theoretical Background and/or Final Technical Report, Section 6 Increased Capability of PROMISC, NASA Grant No. NAG 3-867, Supp. 2, "Probabilistic Lifetime Strength of Aerospace Materials via Computational Simulation").

Execution of the PROMISC code for the example problem whose input is specified in Section 3.1 produces an output file that includes regression or least squares estimates of the exponents (empirical material constants, a_i) in the multifactor interaction equation under the heading BBBB. For example, the constant coefficient (y-intercept, log S_O) is predicted to be 0.6717, the exponent for quasi-static stress to be 0.6449, the exponent for impact to be 0.0000, and so on.

To determine "how well" the data fit the regression equation consider the next subheading in the output file, where R-squared is given. R-squared and the Adjusted R-squared columns give the percentage of the variation in the data which can be explained by the multiple linear regression equation. In this example the multiple linear regression equation explains about 99.7% of the variation. An R-squared value of 100% indicates an exact fit, whereas an R-squared value of 0 % indicates no correlation between the independent variable (strength) and any of the regression variables (effects or primitive variables). This is a first assessment of the adequacy of the model.

In the next heading under ANOVA Table, an alternative statistical measure of "how well" the data fit the "complete" multiple linear regression equation is given. This statistical measure is given in the last column headed by "Prob. of Larger F". This term, known as a p-value, gives the probability that the relationship was due to chance alone and not to the multiple linear regression equation. In this case the probability is virtually zero, which corroborates the observations from the R-squared columns. P-values near zero indicate that the multifactor interaction equation is significant. Thus, we conclude that the multiple linear regression equation is quite effective in predicting strength.

Among the seven regression variables (effects or primitive variables) it is desirable to assess the relative importance of each. From the section headed by BBBB or the one headed by "Inference on Coefficients", the estimates of the exponents in the multifactor interaction equation can be viewed. Since the exponent for impact is virtually zero it can be reasonably assumed that this factor does little to predict the strength. However, it is not wise to be mislead by the mere size of the coefficients. The statistical terms which one should focus on are the "F-statistic" column and the "Prob. of Larger F" column in the section headed by Sequential Statistics. For the first variable, quasi-static stress, the p-value gives the probability that the factor is not significant in the prediction equation. The exponent for quasi-static stress is 0.6449 and the associated p-value is 0.0660, which indicates quasi-static stress is significant. In most statistical circles, p-values near 0.05 or less are considered significant. Moreover, the sixth effect, mechanical fatigue, has a coefficient (exponent of -0.1248) but its p-value is virtually zero. This result indicates that mechanical fatigue (because of its smaller p-value), has greater predictive capability than the quasi-static stress effect. However, both should be considered significant. The remaining factors are completely insignificant.

In outlier detection, use the "Case Analysis" section and the factor, "Cook's D". Cook's D is given first in the second line of each of the forty cases. For example, for observation 1 Cook's D is 37.7568. The larger the value of Cook's D, the farther the observation is away from the center of the data. We consequently note that observation 14, with a Cook's D of 20.0449, has the smallest value, and observation 34, with Cook's D of 50.3682, has the largest value. However even the largest value is well within acceptable ranges indicating that there are no outliers in the data.

The residual column and the standardized residual column can be used to test the hypothesis that errors are normally distributed. In addition, the remaining columns can be used for many statistical purposes in verifying the assumptions in multiple linear regression.

3.2 PROMISC Input For Fixed Model With Actual Experimental Data (240 Data Points)

The 1st line of input (format 2E12.4, see item 1 below) determines the random number generator seed* and the data sample size. The 2nd line (format I3) determines either a fixed or a flexible model. The 3rd line (format I3) chooses the dependent variable as strength. The 4th line (format I3,2X,I3,2X,I3) determines the source of the data (actual experimental, normal or lognormal simulated data). The 5th through the 148th lines (format 5D12.4) specify the data for the primitive variables. This sequence of one hundred forty-five lines repeats for the other primitive variables. Lastly, the 1019th through the 1067th lines specify the data for the strength variable. A table listing the primitive variables, their units and symbols is given in Section 5.0, Appendix A. IMSL parameters are entered as indicated in items 12 and 13.

1. Line 1 selects the Random Number Generator Seed (ISEED) and Sample Size (NTOT).

EXAMPLE:

```
12345678901234567890**
  1       240
```

2. Line 2 selects either Fixed or Flexible Model (MODEL = 0 is flexible, MODEL = 1 is fixed).

EXAMPLE:

```
12345678901234567890
  1
```

3. Line 3 selects strength as the dependent variable (DEPV = 1 is strength dependent variable, DEPV = 0 is not strength dependent variable).

EXAMPLE:

```
12345678901234567890
  1
```

* If actual experimental data are used (AFDS = 0; ADS = 0; AODS = 0) the random number generator seed, ISEED, is read in but not used in the program.

** NOTE: the ruler is to aid the user in formatting and is not a part of the input.

4a. Line 4 specifies the *source* of the data for the three variables within the Quasi-static Stress Effect by using flags. The flag names are AFDS, ADS and AODS. Setting a flag to 0 indicates actual experimental data is directly read from input. Setting a flag to 1 indicates simulated experimental data, normally distributed, is generated by the program via a random number generator. Setting a flag to 2 indicates simulated experimental data, lognormally distributed, is generated by the program via a random number generator. Setting a flag to 3 indicates data not available.

EXAMPLE:

```
12345678901234567890
   0     0     0
```

4b. Lines 5 to 148 contain the actual experimental data for the three variables within the Quasi-static Stress Effect. The Quasi-static Stress Effect variable names have FORTRAN names given in Section 5.0, APPENDIX A.

EXAMPLE:

```
123456789012345678901234567890123456789012345678901234567890
  0.1179D+03  0.1344D+03  0.1273D+03  0.1260D+03  0.1403D+03
  0.1292D+03  0.1295D+03  0.1241D+03  0.1265D+03  0.1229D+03
  0.1321D+03  0.1387D+03  0.1370D+03  031264D+03  0.1323D+03
  0.1278D+03  0.1269D+03...........etc.
```

(All of the values for this and other effects are too numerous to include in this description. See Section 6.0 APPENDIX B.)

5. Lines 149 to 293 input data for the Impact Effect in the same manner as was described for the Quasi-static Stress Effect. The Impact Effect variable names have FORTRAN names given in Section 5.0, APPENDIX A.

EXAMPLE:

```
12345678901234567890
  0     0     0
  0.9870D+00  0.9966D+00  0.1002D+01  0.9997D+00  0.1000D+01
  0.9977D+00  0.9950D+00  0.1001D+01  0.1001D+01  0.1005D+01
  0.9991D+00  0.1000D+01  0.1003D+01  0.9945D+00  0.9952D+00
  0.1000D+00  0.1001D+01............etc.
```

6. Lines 294 to 438 input data for the Temperature Effect in the same manner as was described for the Quasi-static Stress Effect. The Temperature Effect variable names have FORTRAN names given in Section 5.0, APPENDIX A.

EXAMPLE:

```
1234567890123456789012345678901234567890123456789012345678901234567890
  0      0      0
  0.2378D+04   0.2640D+04   0.2789D+04   0.2723D+04   0.2739D+04
  0.2668D+04   0.2598D+04   0.2770D+04   0.2770D+04   0.2856D+04
  0.2708D+04   0.2739D+04   0.2811D+04   0.2583D+04   0.2600D+04
  0.2738D+04   0.2768D+04..........etc.
```

7. Lines 439 to 583 input data for the Chemical Effect in the same manner as was described for the Quasi-static Stress Effect. The Chemical Effect variable names have FORTRAN names given in Section 5.0, APPENDIX A.

EXAMPLE:

```
1234567890123456789012345678901234567890123456789012345678901234567890
  0      0      0
  0.9870D+00   0.9966D+00   0.1002D+00   0.9997D+00   0.1000D+01
  0.9977D+00   0.9950D+00   0.1001D+01   0.1001D+01   0.1005D+01
  0.9991D+00   0.1000D+01   0.1003D+01   0.9945D+00   0.9952D+00
  0.1000D+01   0.1001D+01...........etc.
```

8. Lines 584 to 728 input data for the Creep Effect in the same manner as was described for the Quasi-static Stress Effect. The Creep Effect variable names have FORTRAN names given in Section 5.0, APPENDIX A.

EXAMPLE:

```
1234567890123456789012345678901234567890123456789012345678901234567890
  0      0      0
  0.9072D+04   0.1034D+05   0.9792D+04   0.9696D+04   0.1080D+05
  0.9936D+04   0.9959D+04   0.9544D+04   0.9733D+04   0.9450D+04
  0.1016D+05   0.1067D+05   0.1054D+05   0.9723D+04   0.1018D+05
  0.9827D+04   0.9758D+04.........etc.
```

9. Lines 729 to 873 input data for the Impact Effect in the same manner as was described for the Quasi-static Stress Effect. The Impact Effect variable names have FORTRAN names given in Section 5.0, APPENDIX A.

EXAMPLE:

```
1234567890123456789012345678901234567890123456789012345678901234567890
   0      0      0
   0.5749D+01   0.7465D+01   0.6696D+01   0.6565D+01   0.8136D+01
   0.6894D+01   0.6926D+01   0.6362D+01   0.6615D+01   0.6237D+01
   0.7214D+01   0.7947D+01   0.7752D+01   0.6602D+01   0.7235D+01
   0.6744D+01   0.6649D+01.........etc.
```

10. Lines 874 to 1018 input data for the Thermal Fatigue Effect in the same manner as was described for the Quasi-static Stress Effect. The Thermal Fatigue Effect variable names have FORTRAN names given in Section 5.0, APPENDIX A.

EXAMPLE:

```
1234567890123456789012345678901234567890123456789012345678901234567890
   0      0      0
   0.2464D+01   0.3199D+01   0.2870D+01   0.2813D+01   0.3487D+01
   0.2954D+01   0.2968D+01   0.2727D+01   0.2835D+01   0.2673D+01
   0.3092D+01   0.3406D+01   0.3322D+01   0.2830D+01   0.3101D+01
   0.2890D+01   0.2850D+01.........etc.
```

11a. Line 1019 specifies the source of the strength data by using flags. The flag names are AFDS, ADS and AODS. Setting a flag to 0 indicates actual experimental data is directly read from input. Setting a flag to 1 indicates simulated experimental data, normally distributed, is generated by the program via a random number generator. Setting a flag to 2 indicates simulated experimental data, lognormally distributed, is generated by the program via a random number generator. Setting a flag to 3 indicates data not available.

EXAMPLE:

```
1234567890
   0
```

11b. Lines 1020 to 1067 contain the actual experimental data for strength. The FORTRAN name for strength is STR.

EXAMPLE:

```
1234567890123456789012345678901234567890123456789012345678901234567890
   0.1112D+02   0.8518D+01   0.7325D+01   0.7826D+01   0.7708D+01
   0.8277D+01   0.8921D+01   0.7464D+01   0.7464D+01   0.6842D+01
   0.7954D+01   0.7729D+01   0.7166D+01   0.9028D+01   0.8875D+01
   0.7711D+01   0.7478D+01.........etc.
```

12. The CORVC [1] parameters are IDO, LDX, IFRQ, IWT, MOPT, ICOPT, LDCOV, and LDINCD and are entered in that order as follows (line 1068):

EXAMPLE:

```
1234567890123456789012345678901234567890
       0  240      0       0       0       1      19      19
```

13. The RCOV [1] parameters are INTCEP, NOND, NDEP, LDCOV, LDB, LSR, and LDSCPE and are entered in that order as follows (line 1069):

EXAMPLE:

```
1234567890123456789012345678901234567890
       1       7       1      19      19      19       1
```

3.2.1 Discussion of Results

Execution of PROMISC (source code entitled PROMISC5.FOR) produces an output file that gives computed values for the empirical material constants, a_i. Output also includes statistics and diagnostics that enhance the PROMISC multiple linear regression analysis (see Section 2.0, Theoretical Background and/or Final Technical Report, Section 6 Increased Capability of PROMISC, NASA Grant No. NAG 3-867, Supp. 2, "Probabilistic Lifetime Strength of Aerospace Materials via Computational Simulation").

Execution of the PROMISC code for the example problem whose input is specified in Section 3.2 produces an output file that includes regression or least squares estimates of the exponents (empirical material constants, a_i) in the multifactor interaction equation under the heading BBBB. For example, the least squares estimate of the constant term (y-intercept, log S_O) is predicted to be 4.99, quasi-static stress to be 0.14, mechanical fatigue to be -0.05, and so on.

To see "how well" the data fit the regression equation, consider the subheading which contains R-squared. From the R-squared coefficients, it can be observed that about 99.99% of the variation in the data can be explained by the regression equation. Recall that 100% is the value when the model is exact. Under the next subheading, the ANOVA Table helps to quantify the model adequacy in terms of probability. Under the source "regression" it is observed that the p-value is virtually zero. The asterisks in the "Overall F" column indicate the F-statistic exceeded 99,999.99 and therefore could not be displayed in the space allocated.

Among the seven factors (effects or primitive variables) in the multifactor interaction equation, we can associate relative importance with the size of the p-values in the "Sequential Statistics" Table. The smaller the p-value (i.e., "Prob. of Larger F") then the more significance associated with the factor. Notice that factors 1, 2 and 5 are significant with p-values below the 0.05 level. However factors 3, 4, 6 and 7 are insignificant. Therefore, it may be beneficial to reanalyze the data by deleting factors 3, 4, 6 and 7.

To look for outlying observations, the "Case Analysis" Table is used. The column headed by "Cook's D" is used for the detection of aberrant observations. The output is complicated in this case by the number of observations present in the data set. As explained in Section 3.1.1, the larger values of "Cook's D" indicate observations which are further away from the center of the data. However, when 240 observations are present the process of scanning the values of Cook's D is more tedious. Observation 85 is the one with the largest Cook's D of 0.0592 and standardized residual of 2.6871, both of which are within acceptable limits.

The residuals and standardized residuals can be used to test the assumptions of normality for the errors.

3.3 General PROMISC Program Notes

1. Any effect data, $\left[\frac{A_F - A}{A_F - A_o}\right]$, not included in the model is set to zero.

2. Fatigue cycles should be input as log cycles rather than as cycles. Reasons are the same as for PROMISS.

3. Strength response, S, should be input as strength in MPa or ksi. PROMISC will internally calculate log S.

4. The stress data effect in PROMISC has not been customized for negative lognormal values as it has been for PROMISS.

4.0 REFERENCES

1. IMSL, "STAT/LIBRARY, FORTRAN Subroutines for Statistical Analysis", Houston, Texas.

2. SAS Institute, Inc., SAS/GRAPH User's Guide, Version 5 Edition, Cary, NC: SAS Institute, Inc., 1985, p. 596.

3. Chamis, C.C., "Simplified Composite Micromechanics Equations for Strength, Fracture Toughness, Impact Resistance and Environmental Effects," NASA TM 83696, Jan., 1984.

4. Hopkins, D.A., "Nonlinear Analysis for High-Temperature Multilayered Fiber Composite Structures," NASA TM 83754, Aug., 1984.

5. Chamis, C.C. and Hopkins, D., "Thermoviscoplastic Nonlinear Constitutive Relationships for Structural Analysis of High Temperature Metal Matrix Composites," NASA TM 87291, Nov., 1985.

6. Hopkins, D. and Chamis, C.C., "A Unique Set of Micromechanics Equations for High Temperature Metal Matrix Composites," NASA TM 87154.

7. Ross, S.M., Introduction to Probability and Statistics for Engineers and Scientists, Wiley, N.Y., 1987, p.278.

8. Siddall, J.N., "A Comparison of Several Methods of Probabilistic Modeling," Proceedings of the Computers in Engineering Conference, ASME San Diego, CA, Vol. 4, 1982, pp. 231-238.

9. Scott, D.W., "Nonparametric Probability Density Estimation by Optimization Theoretic Techniques," NASA CR-147763, April, 1976.

5.0 APPENDIX A

PRIMITIVE VARIABLES, SYMBOLS, AND UNITS

Table A1.2 Primitive variables, symbols, and units for PROMISS

Primitive Variables (Effect)	Theory Symbol	FORTRAN Name	Units SI	U.S.
<u>QUASI-STATIC STRESS EFFECT</u>				
Ultimate value	S_{SF}	AF	MPa	ksi
Current value	σ_S	A	MPa	ksi
Reference value	σ_{SO}	AO	MPa	ksi
<u>IMPACT EFFECT</u>				
Ultimate value	S_{DF}	AF2	Dimensionless	
Current value	σ_D	A2	Dimensionless	
Reference value	σ_{DO}	AO2	Dimensionless	
<u>OTHER MECHANICAL EFFECTS</u>				
Ultimate value	A_{3F}	AF3	Dimensionless	
Current value	A_3	A3	Dimensionless	
Reference value	A_{3O}	AO3	Dimensionless	
<u>TEMPERATURE</u>				
Ultimate value	T_F	AF4	^oC	^oF
Current value	T	A4	^oC	^oF
Reference value	T_O	AO4	^oC	^oF
<u>THERMAL SHOCK</u>				
Ultimate value	A_{5F}	AF5	Dimensionless	
Current value	A_5	A5	Dimensionless	
Reference value	A_{5O}	AO5	Dimensionless	

Primitive Variables (Effect)	Theory Symbol	FORTRAN Name	Units SI	U.S.
OTHER THERMAL EFFECTS				
Ultimate value	A_{6F}	AF6	Dimensionless	
Current value	A_6	A6	Dimensionless	
Reference value	A_{6O}	AO6	Dimensionless	
CHEMICAL REACTION				
Ultimate value	R_F	AF7	Dimensionless	
Current value	R	A7	Dimensionless	
Reference value	R_O	AO7	Dimensionless	
RADIATION				
Ultimate value	A_{8F}	AF8	Dimensionless	
Current value	A_8	A8	Dimensionless	
Reference value	A_{8O}	AO8	Dimensionless	
OTHER EFFECTS				
Ultimate value	A_{9F}	AF9	Dimensionless	
Current value	A_9	A9	Dimensionless	
Reference value	A_{9O}	AO9	Dimensionless	
CREEP				
Ultimate value	t_{CF}	AF10	Hours	Hours
Current value	t_C	A10	Hours	Hours
Reference value	t_{CO}	AO10	Hours	Hours
MECHANICAL FATIGUE				
Ultimate value	N_{MF}	AF11	log of cycles	
Current value	N_M	A11	log of cycles	
Reference value	N_{MO}	AO11	log of cycles	

Primitive Variables (Effect)	Theory Symbol	FORTRAN Name	Units SI	U.S.
OTHER TIME DEPENDENT MECHANICAL EFFECT				
Ultimate value	A_{12F}	AF12	Dimensionless	
Current value	A_{12}	A12	Dimensionless	
Reference value	A_{12O}	AO12	Dimensionless	
THERMAL AGING				
Ultimate value	A_{13F}	AF13	Dimensionless	
Current value	A_{13}	A13	Dimensionless	
Reference value	A_{13O}	AO13	Dimensionless	
THERMAL FATIGUE				
Ultimate value	N_{TF}	AF14	log of cycles	
Current value	N_{T}	A14	log of cycles	
Reference value	N_{TO}	AO14	log of cycles	
OTHER TIME-DEPENDENT THERMAL EFFECTS				
Ultimate value	A_{15F}	AF15	Dimensionless	
Current value	A_{15}	A15	Dimensionless	
Reference value	A_{15O}	AO15	Dimensionless	
CORROSION				
Ultimate value	A_{16F}	AF16	Dimensionless	
Current value	A_{16}	A16	Dimensionless	
Reference value	A_{16O}	AO16	Dimensionless	
SEASONAL ATTACK				
Ultimate value	A_{17F}	AF17	Dimensionless	
Current value	A_{17}	A17	Dimensionless	
Reference value	A_{17O}	AO17	Dimensionless	

Primitive Variables (Effect)	Theory Symbol	FORTRAN Name	Units SI	U.S.
<u>OTHER TIME-DEPENDENT EFFECT</u>				
Ultimate value	A_{18F}	AF18	Dimensionless	
Current value	A_{18}	A18	Dimensionless	
Reference value	A_{18O}	AO18	Dimensionless	

6.0 APPENDIX B

PROMISC SAMPLE PROBLEM: INPUT AND OUTPUT FILES

Sample problems are discussed in sections 3.1 and 3.2. One sample problem corresponds to each section. The input and output file names for each sample problem are listed below. The enclosed disk also includes the same files.

3.1 PROMISC Input For Fixed Model With Actual Experimental Data (40 Data Points)

Input File(s): 31PRC4.INP
Output File: 31PRC4.OUT

3.2 PROMISC Input For Fixed Model With Actual Experimental Data (240 Data Points)

Input File(s): 32PRC5.INP
Output File: 32PRC5.OUT

7.0 APPENDIX C

IMSL SUBROUTINE CALLS FROM PROMISC

1. RNSET - Initializes a random seed for use in the IMSL random number generators.
2. RNNOR - Generates pseudorandom numbers from a standard normal distribution using an inverse CDF method.
3. RNLNL - Generates pseudorandom numbers from a lognormal distribution.
4. CORVC - Generates sums of squares and crossproducts.
5. RCOV - Performs the multiple linear regression.
6. RSTAT - Computes statistics related to the regression.
7. RCASE - Computes further statistics and diagnostics related to the regression.
8. Other IMSL Subroutines - SSCAL, SADD, UMACH, WRRRN, and WRIRN.